Direct-Write Lithography of sub-10nm Features on Metallorganic Resists using a Helium Ion Microscope

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Fabrication of sub-10nm features of metals and metal oxides has been a challenge due to the limitation imposed by resists and the lift off process in traditional lithographic methods. Direct write nanolithography using metal-organic resists have been established as alternatives to the conventional lithographic approach to fabricate nanoscale features of metals and metal oxides.[1-2] In this work we evaluate two metallorganic resists to directly pattern metal nanostructures, nickel naphthenate and palladium mercaptide using the Helium Ion Microscope. These resist behave with a negative tone upon exposure with the helium ion beam. The small probe size of the helium ion beam (0.5 nm) enables fabrication of very high aspect ratio structures with line widths below 10nm.[3] The resists were spincoated on silicon substrates and patterned with a focused 40keV helium ion beam at a current of 0.2 pA. After solvent development the smallest line width observed in these patterns is 9nm, Figure 1. The patterns exhibit no proximity effect as seen in the nested L patterns on nickel naphthenate, Figure 2. TEM analysis of these fine patterns shows an increase in line width with the fluence, Figure 3. The lines are 8nm wide with line edge roughness less than 1nm corresponding to fluence of $300 \mu C/cm^2$, Figure 3a. The white speckles are interpreted as the amorphous matrix of nickel and hydrocarbons. Around $5 mC/cm^2$ there is a core structure with exposure along the periphery. This exposure in the sides may be attributed to over-exposure due to the insulating substrate or pyrolysis. Further analysis using a non-insulating substrate to eliminate the charging effect is underway. Rutherford Backscattering Spectroscopy has been employed to study the composition of the structures patterned at different ion fluences. Reduction methods to enhance metal content and other processes to achieve smaller features and high aspect ratio structures are currently being explored.

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[1] M.S.M. Saifullah, K.R.V. Subramanian, E. Tapley, Dae-Joon Kang, M.E. Welland and M. Butler, Nano Lett. **3**, 11 (2003)
[2] T. Bhuvana and G. U. Kulkarni, ACS Nano **2**, 3 (2008)
[3] B. Ward, J. Notte, and N. Economou, *J. Vac. Sci. Technol. B* **24**, 6 (2006)

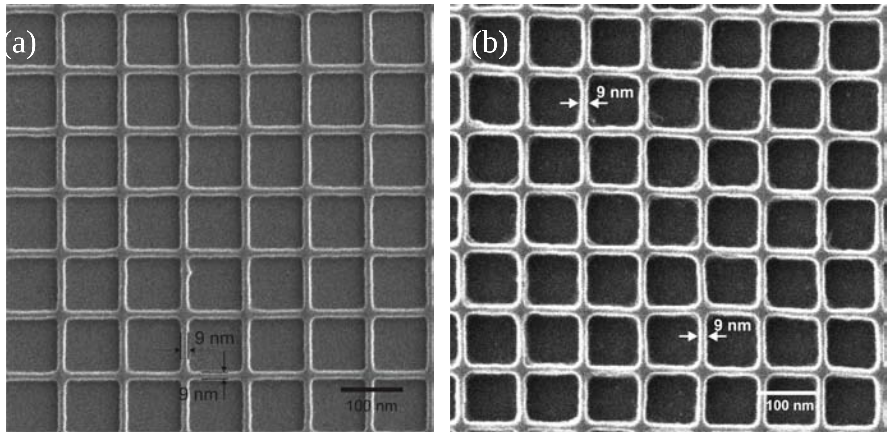

Figure 1: Grid patterns with a line spacing of 100nm and line width of 9nm patterned with a helium ion beam of energy 40keV and current of 0.2 pA on (a) nickel naphthenate at ion fluence of 3mC/cm^2 and (b) palladium mercaptide at ion fluence of 100μC/cm^2

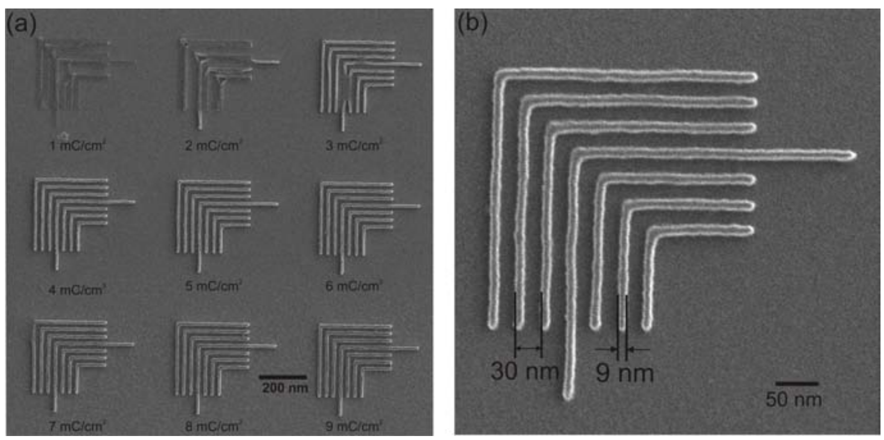

Figure 2: (a) Nested L dose matrix (1-9mC/cm^2) on nickel naphthenate with pitch of 30nm (b)Magnified image of the nested L pattern with a line width of 9nm corresponding to 5mC/cm^2

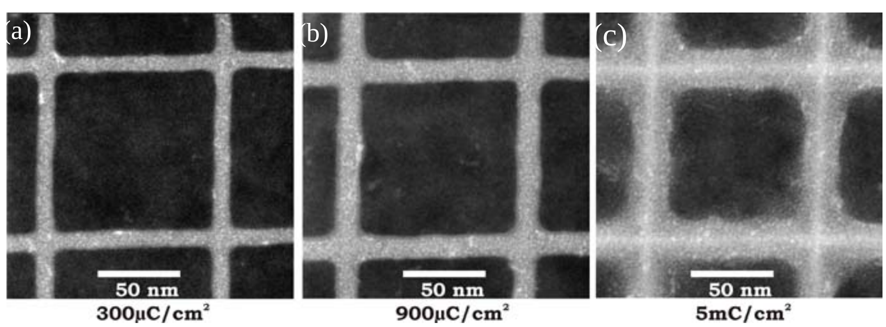

Figure 3: STEM dark field image of grid patterns on nickel naphthenate coated on silicon nitride membranes with a helium ion beam of energy 40keV and current of 0.2 pA at ion fluence of (a) 300μC/cm^2, (b) 900μC/cm^2 and (c) 5mC/cm^2. The line width corresponding to 300μC/cm^2 is 8nm. The line width increases with fluence. At higher rates of ion irradiation the insulating substrate and pyrolysis effects introduce a peripheral exposure as seen in (c)